Development of a Portable Optical Time Domain Reflectometer System in Photonic Integration Technology

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ABSTRACT

In this work we present and discuss a concept of an integrated optical time domain reflectometer realized in indium phosphide generic integration technology. The proof-of-the-concept chip has been designed, manufactured and tested with respect of applicability in real measuring systems. In general, the correctness of the proposed approach has been confirmed, simultaneously indicating necessary modifications of the design. As a result, the optimized variants of the photonic integrated circuit have been proposed.

Keywords: optical time domain reflectometer, application specific photonic integrated circuit, generic integration technology, indium phosphide

1. INTRODUCTION

Optical time domain reflectometry (OTDR) is a measurement technique commonly used for characterization of optical fibers and fiber-optic communication systems [1]. It utilizes the phenomena of the Rayleigh backscattering and Fresnel reflections – a series of laser pulses is launched to an optical fiber and the power of the returning signal is monitored in the time domain. Careful analysis and processing of the recorded time traces enables extraction of the most important parameters of optical links such as attenuation of fibers, losses at splices and connectors, length of the links and location of the events with respect to the distance to the reflectometer. It also allows localizing breaks, damages or deformations present in a fiber-optic link. A substantial advantage of the reflectometry techniques is the ability to perform measurements while having access to the single end of an optical fiber only, which is essential for application in already deployed telecom networks.

Optical time domain reflectometer systems, which are currently available on the market, can be divided into two major groups depending on the application targeted. Highly advanced equipment of excellent performance in terms of dynamic range, maximal measurement distance and accuracy is mostly used by optical fiber manufacturers and in specialized laboratories. For such equipment, the compact size and energy consumption level are obviously not of primary concern – state-of-the-art devices are rather bulky and power hungry. Furthermore, interpretation of the results requires professionally trained and highly skilled personnel, which limits common use of this type of devices by technicians in the field.

On the contrary, portable OTDRs are typically used for diagnostics of the network in central offices or in the field. The main requirements for the portable devices are quite obvious – small size and weight, low energy consumption, compatibility with battery supply and low cost of manufacturing. These are complemented by the demand of the prompt, automated interpretation of the results. The continuous evolution of telecommunication and sensing networks into all fiber-optic systems leads to the conclusion that the market for portable OTDR devices will dynamically increase. In this work we propose a novel optical time domain reflectometer system, which is realized in a form of a monolithic application specific photonic integrated circuit. The devices have been designed and manufactured in the generic integration technology on indium phosphide technology platforms. Two generations of optical chips are demonstrated and discussed with respect of applicability in real measuring systems.

2. PHOTONIC INTEGRATED CIRCUIT – 1st GENERATION

The scheme of the first generation of integrated OTDR modules is presented in Figure 1. It comprises a directly modulated DFB laser, operating around 1550 nm, as the source of the optical pulses. The laser is connected to a 2×2 MMI coupler, the outputs of which are routed to a spot-size-converter, which enables edge-coupling of the signal to an analyzed optical fiber, and to an integrated PIN photodiode, which provides time-domain monitoring of the outgoing pulses. The remaining input of the coupler is connected to another PIN photodiode, responsible for detection of the backscattered and reflected light. Figure 1 presents also the mask layout of the circuit of dimensions 6 mm × 1 mm, which was placed in a standard cell of the Heinrich Hertz Institute process [2], and a microscope picture of the chip fabricated in the generic process provided by HHI on a multi-project wafer.

The fabricated chips were mounted on a copper block and thermally stabilized during the measurements. Optical coupling was provided through a cleaved SMF fiber due to the presence of spot-size-converters at the chip outputs. The interface of the DFB laser is compatible with the G-S-G high-speed electrical probes, which were used for driving both with a DC bias and pulsed signals. Static measurements have proven the basic performance of the laser – the maximum fiber-coupled power is around 0.75 mW while driven at 150 mA, the laser operates on a single mode (λ = 1546.5 nm) with side mode suppression ratio around 45 dB.

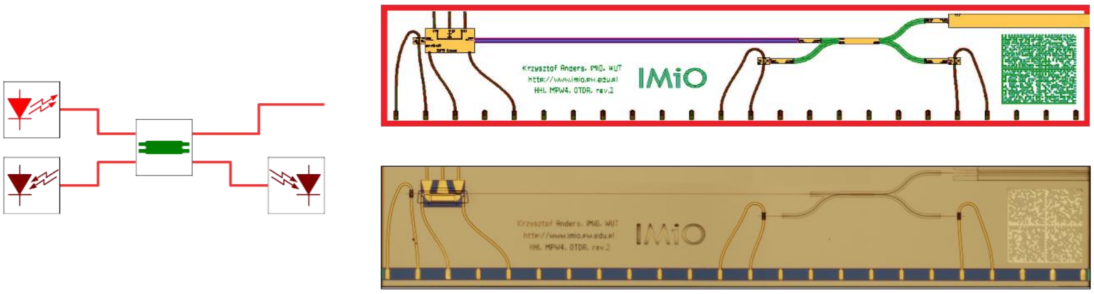

Fig. 1. Circuit scheme, mask layout and a microscope picture of the first generation of integrated optical time domain reflectometer.

Dynamic measurements were performed with the use of a pulsed signal of a different time duration (between 20 ns and 20 µs) and constant repetition rate (f = 1 kHz) driving the DFB laser. The output of the chip was connected to a spool of single mode fibers of different length (5-20 km). The photocurrent from the photodiode (reverse bias of 2.0 V) was amplified using a transimpedance amplifier and visualized on the oscilloscope. Additionally, a discrete photodetector was connected as a reference to the end of the analyzed fiber link.

Figure 2 presents the recorded time traces for different conditions and configurations of the characterization setup. It should be noted that without averaging the signal, the trace suffers from significant noise, which is clearly visible in Figure 2a. This phenomenon is quite typical for reflectometric measurements, the signal-to-noise ratio increases with the number of recorded samples (square-root dependence). The improvement of the signal quality is visible in Figure 2b, for which 8192 samples were taken. Three pulses can be distinguished in the graph. The first, strong blue pulse, is a result of reflection at the chip facet and defines the reference of the OTDR trace (zero time point). The second (red pulse) is detected by the external photodetector and corresponds to a single pass of the pulse – from the source to the end of the fiber link. The third (weak blue) pulse is a result of a double pass – from the source to the end and after reflection at the end back to the source. The time difference of approximately 24 µs between consecutive pulses corresponds well to the length of the analyzed link of 5 km.

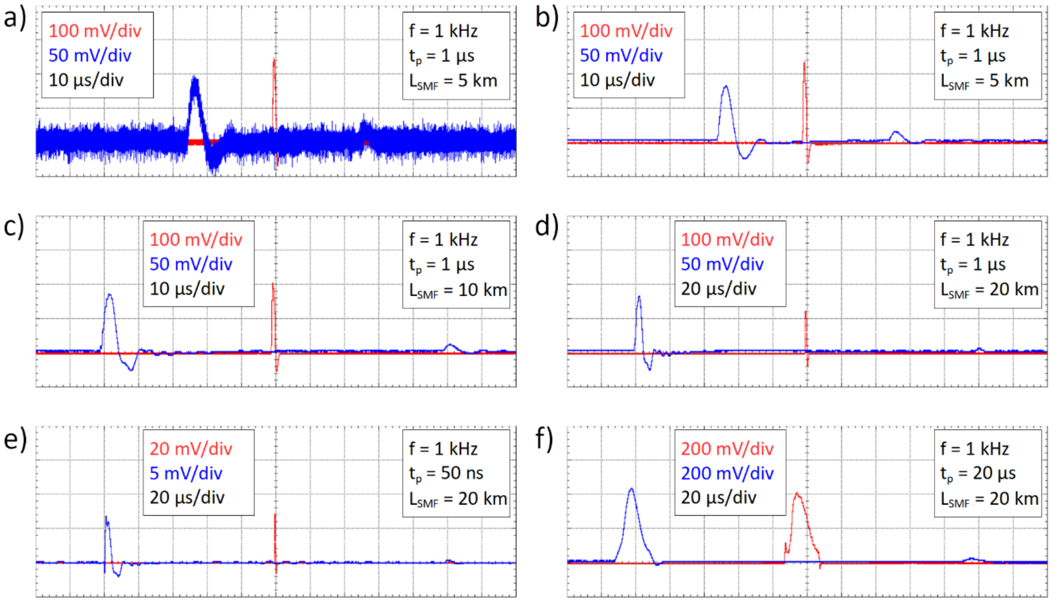

Fig. 2. Recorded time traces for OTDR experiments.

The performance of the OTDR system was tested for different conditions and the obtained results are visualized in Figures 2c-2f. For the length of the link up to 20 km, a detectable reflection at the end of the fiber was observed for pulse duration in the range between 50 ns and 20 µs. For the pulses shorter than 50 ns the signal was too low to be detected.

3. PHOTONIC INTEGRATED CIRCUIT – 2nd GENERATION

The second generation of the integrated OTDR unit comprises a number of test circuits, designed for determining a solution of the best performance. The circuits were realized using the SMART Photonics technology platform. As light sources either Fabry-Perot or DBR lasers are used. External modulation is provided either by an electro-absorption section or a Mach-Zehnder interferometer with electro-optic phase shifters. Every laser-modulator combination is designed in two variants – with and without a booster semiconductor optical amplifier, positioned prior to the output 2×2 MMI coupler. Each circuit uses a PIN photodiode with a ground-signal-ground electrical interface for monitoring of the backscattered and reflected signal. The main difference in comparison to the first generation circuits is the presence of the booster amplifier (the Rayleigh signal for the first generation circuit was too weak to be detected) and a photodiode with a high-speed electrical interface (the electro-optical bandwidth is 18 GHz) in order to avoid the ringing effect. Furthermore, the chip outputs are angled, so that the influence of the parasitic reflection at the facet is minimized.

Figure 3a presents the circuit scheme for the variant with the Mach-Zehnder modulator (MZM), with both types of lasers at its inputs. The outputs of the MZM are then connected either directly or through an SOA to the output coupler. Such a circuit provides a possibility of testing two types of lasers with and without a booster, which is an equivalent to four distinct circuits. On the contrary, as the electro-absorption modulator has only a single input and output, for independent circuits have been designed – Figure 3b presents two variants, which are realized with both types of lasers. Mask layout of the designed cell is presented in Figure 3c. The chips are currently being fabricated in the SMART Photonics laboratories.

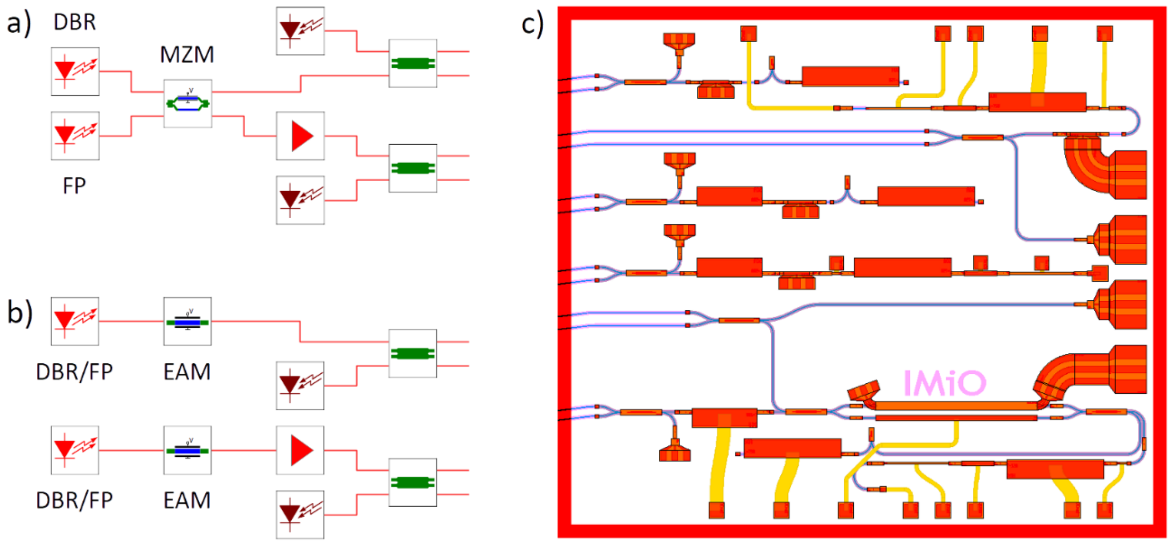

Fig. 3. Circuit scheme and mask layout of the second generation of integrated optical time domain reflectometers.

Simultaneously we have initiated R&D works on the development of the electronic circuitry for precise controlling the key parameters of the laser and detector as well as processing all gathered data. After solving all problems with powering, stabilizing, steering and data processing the "classical" electronic circuits are planned to be replaced by a dedicated electronic integrated circuit (EIC) it the final version of the device.

SUMMARY

Two generations of integrated units for portable optical time domain reflectometers have been demonstrated. The proof-of-the-concept device has been designed, manufactured and tested with respect of applicability in real measuring systems. In general, the correctness of the proposed approach has been confirmed, simultaneously indicating necessary modifications of the design, mostly with respect to the level of the output optical power, parasitic reflections and photodetectors bandwidth. An optimized design of the photonic circuit has been proposed.

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